ORIGINS Excellence Cluster

SFB 1258 | Neutrinos Dark Matter Messengers

Max-Planck-Institut für Physik (Werner-Heisenberg-Institut)

Technische Universität München

Enhanced galactic center gamma-rays from dark matter annihilation

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Introduction 1

Fundamental question:
What constitutes dark matter (DM)?

Possible answer:
Strongly interacting massive particles:

- **DM-DM** $\mathbf{n}-$ **body processes.** → $\chi^n \to \chi\chi$: n-body interaction $\langle \sigma v^{n-1} \rangle$
  - Weak DM-SM interaction. → $\chi\chi \to \gamma\gamma$: annihilation into photons $\langle \sigma v \rangle_{\rm ann}$
    - Mass $m \lesssim$ GeV.

Two processes:

$\chi^n \to \chi\chi$: n-body interaction $\langle \sigma v^{n-1} \rangle$

$\chi\chi \to \gamma\gamma$: annihilation into photons $\langle \sigma v \rangle_{\rm ann}$

Why?
DM **production mechanism** (freeze-out) predicts correct DM abundance today. ⇒

$\langle \sigma v^{n-1} \rangle (m)$
which reproduces current DM density

Introduction 2

Further signals:

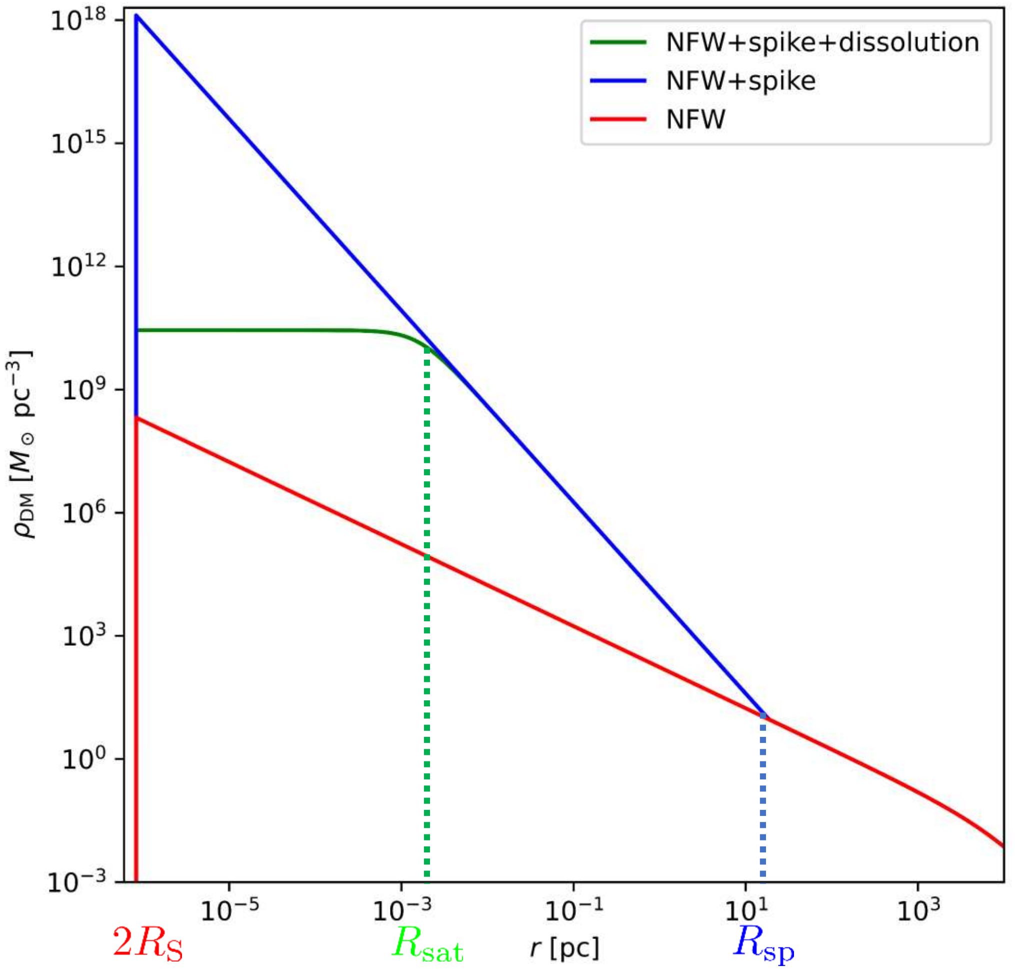
Photons from **Galactic Center (GC)** region of Milky Way (MW) because:

- Strength of signal $\propto \rho^n$.
- BH at GC induces larger density near it (**spike**).
- Proximity to the Earth.

Our idea:

- $n-$ body processes will amplify the signal $(\propto \rho^n)$.
- Is the amplification large enough (limited by cross section).
- What constraints can we obtain?

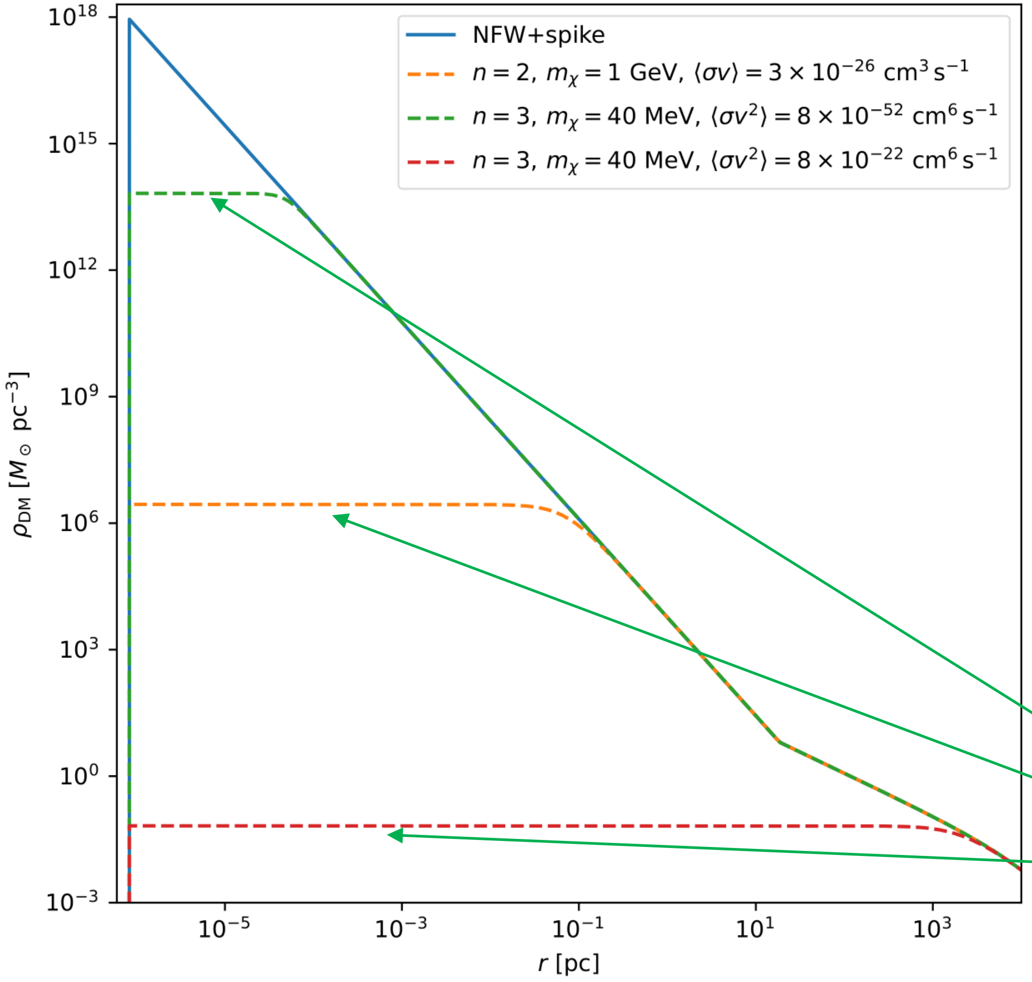
Galactic center DM density profile



- Halo: Far from the GC, from N-body simulations (NFW).
- Spike: Due to gravitational influence of central BH, DM density increases dramatically.
- Saturation: DM number-changing processes reduce the DM density close to the BH.

$$\rho(r) = \begin{cases} 0 & r < 2R_S \\ \rho_{\rm sat} & 2R_S \le r < R_{\rm sat} \\ \rho_{\rm spike}(r) & R_{\rm sat} \le r < R_{\rm sp} \\ \rho_{\rm halo}(r) & r \ge R_{\rm sp} \end{cases},$$

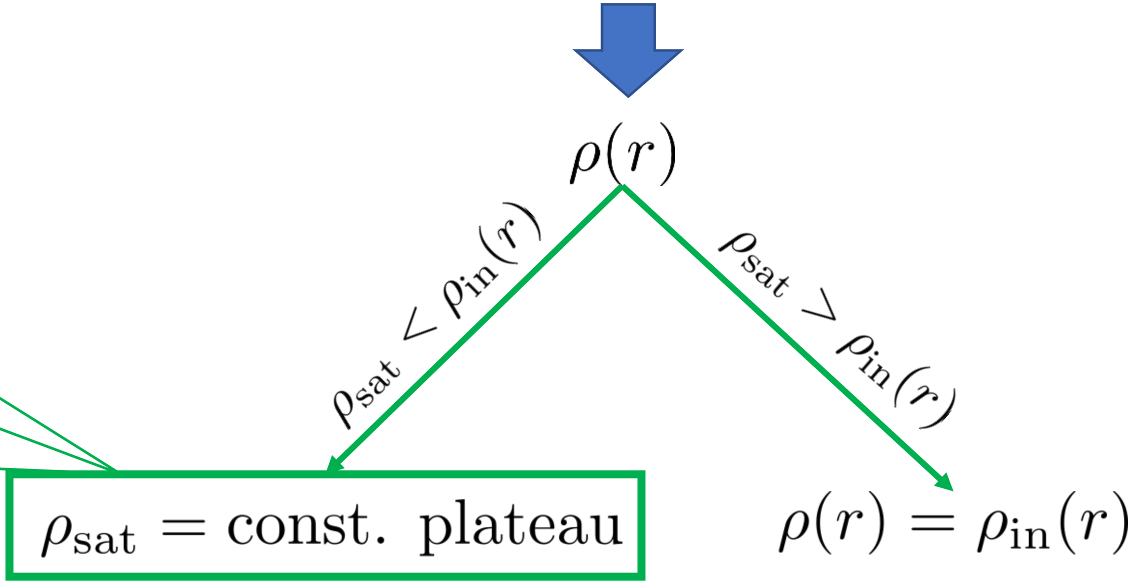
Influence of DM interactions on density: Saturation



DM annihilations reduce the DM density

The effect will be enhanced for:

- Stronger interaction.
- Larger n.



Astrophysical J-factor

J-factor stands for all astrophysical modelling

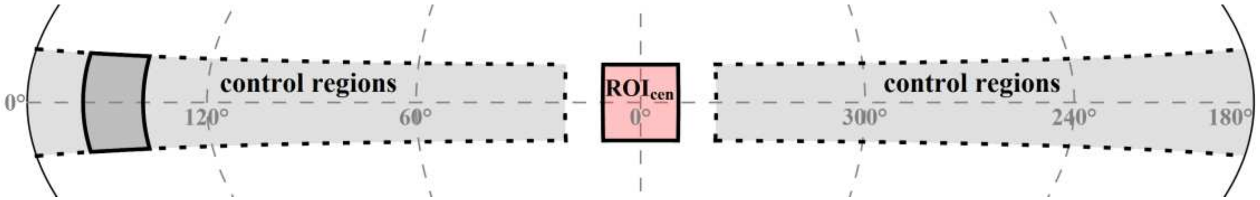
$$J_n(\theta) = \int_{\mathrm{l.o.s}} \frac{ds}{r_\odot} \left(\frac{\rho(r(s,\theta))}{\rho_\odot} \right)^n$$

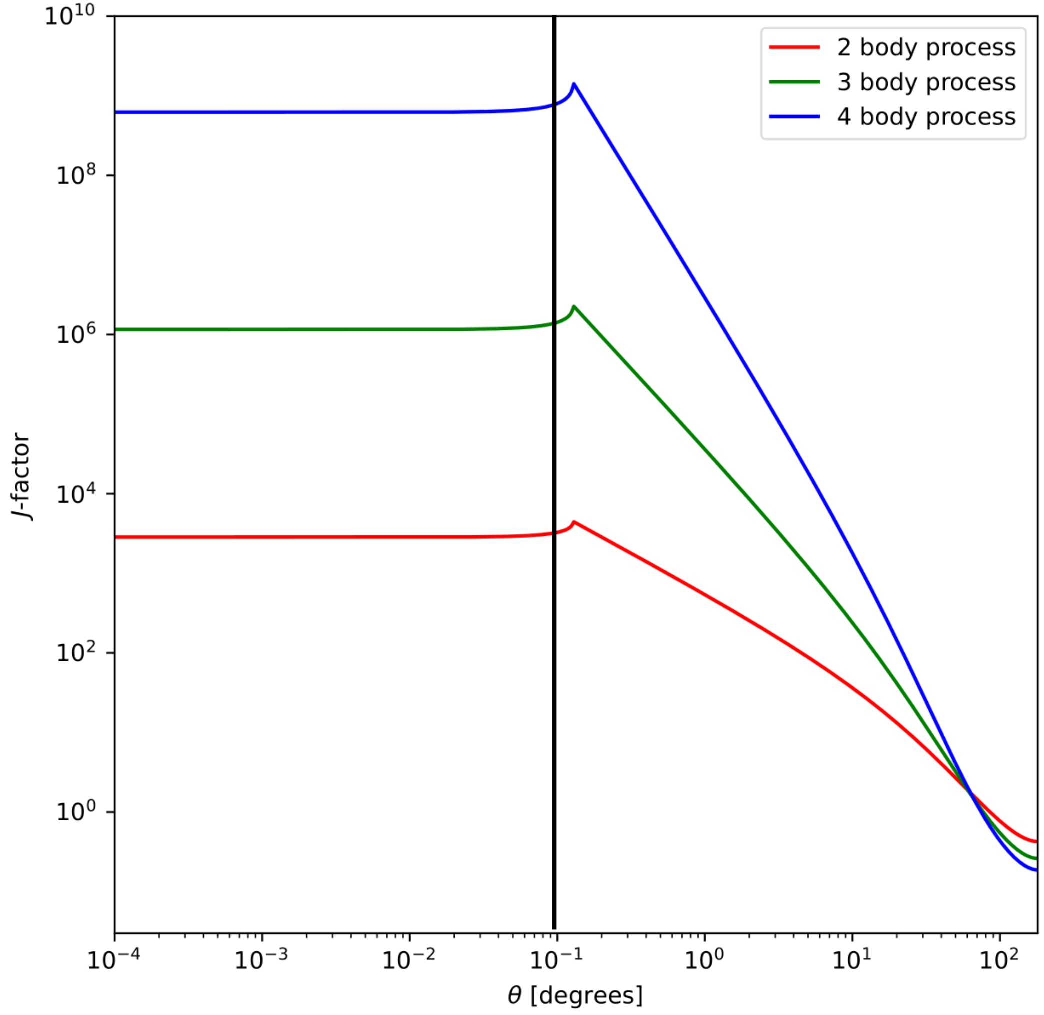
* θ is the angle between the line of sight direction and the Earth-GC axis

- As n increases, so does the J-factor.
  - Especially for **small angles**.

Good reason to **expect** enhancement of the signal, <u>especially from GC</u>.

Why?





Region of interest

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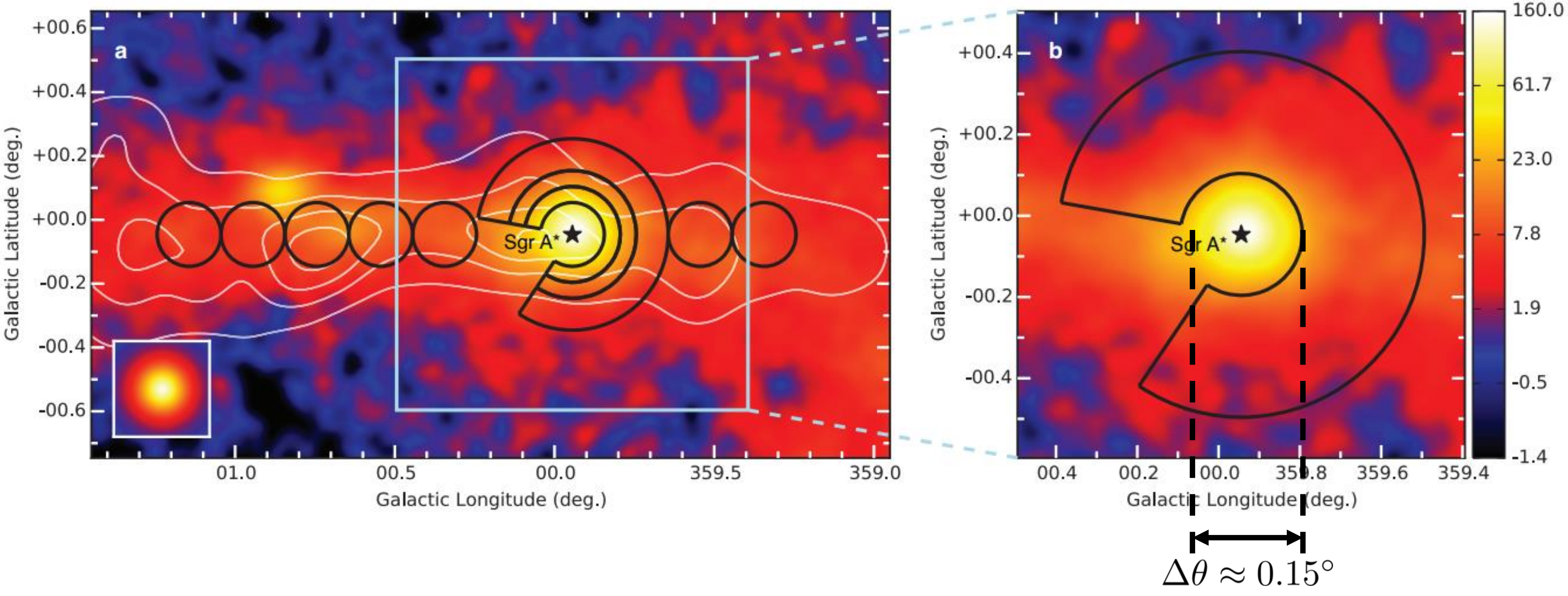
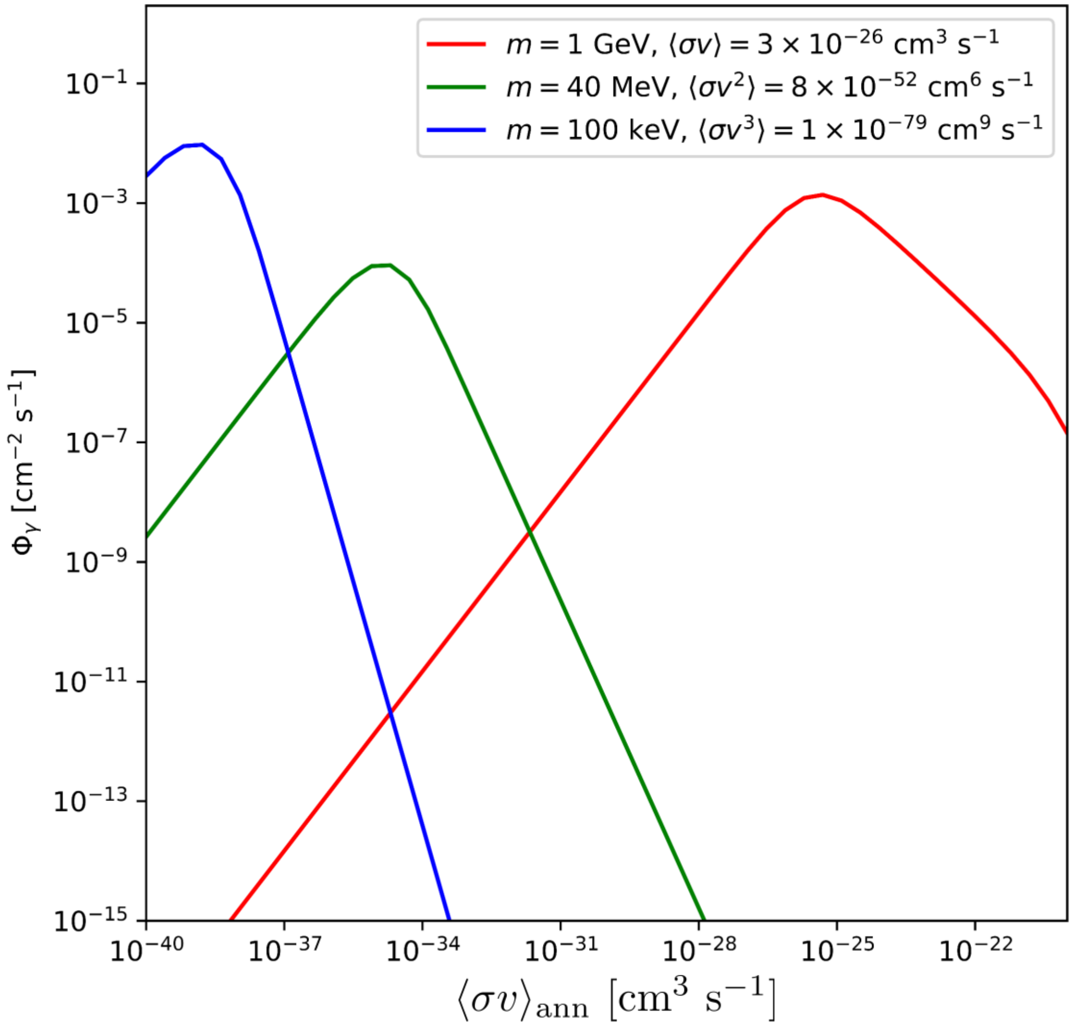


- Angular resolution of GC: $10^{-1°}$
- Region where J-factor is maximized!

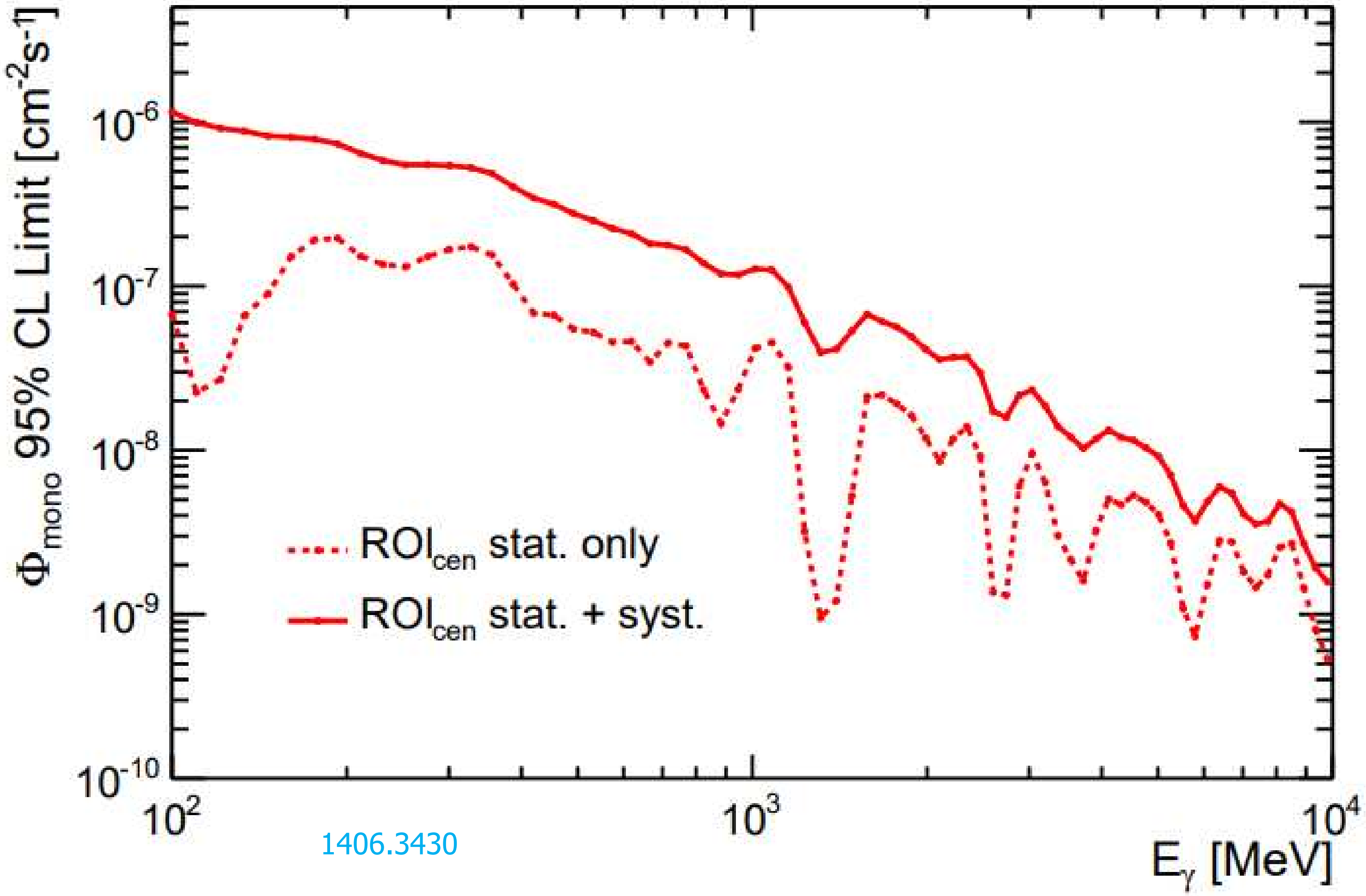
Flux from DM interactions

Photon flux		
$\frac{d\Phi_\gamma}{d\Omega} \propto f\left(\langle\sigma v^{n-1}\rangle, \langle\sigma v\rangle_{\text{ann}}\right) J_n(\theta)$		
$\langle\sigma v\rangle_{\text{ann}}$ increases	>>>	<<<

- Each $n-$body process maximizes the flux for a different region of $\langle\sigma v\rangle_{\text{ann}}$.
  - For an $n=3$ body process, we know $\langle\sigma v^2\rangle(m)$ that gives us the observed DM density according to freeze-out.
- We can set constraints on $\langle\sigma v\rangle_{\text{ann}}$ for the $n=3$ case.



Data: *Fermi*-LAT observations



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DM annihilation into photons leads to a **line spectrum**.

- *Fermi*-LAT (Large Area Telescope) observations between 2008 and 2013.
- GC observations of a **0.5° square** around the GC.
- Search for photon **spectral lines** from 100 MeV to 10 GeV.

*Mass $m \lesssim$ GeV.

Constraints

Fermi-LAT constraints

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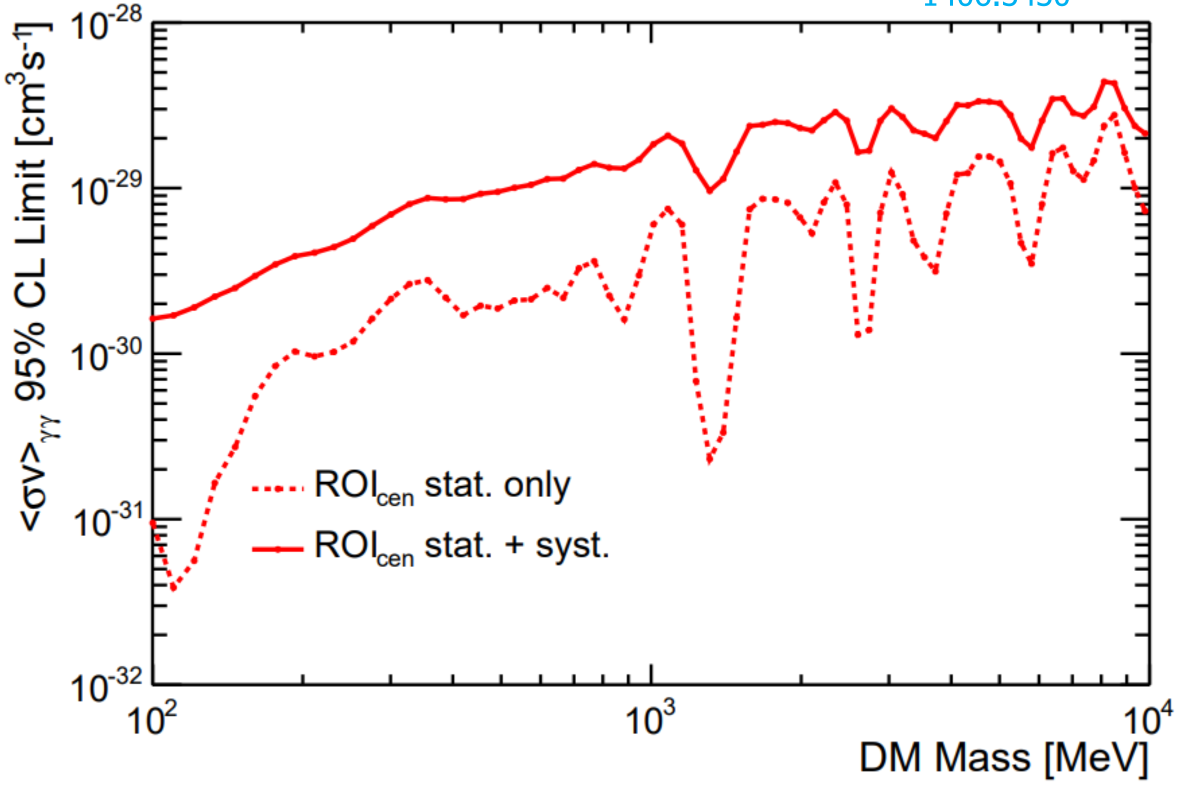
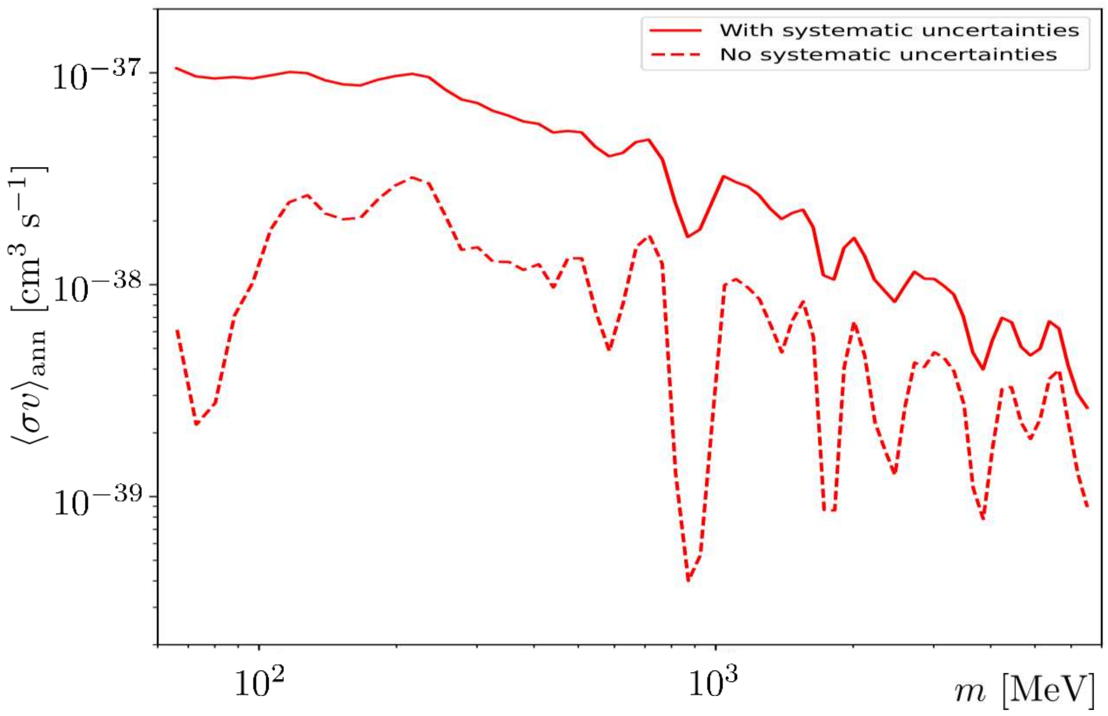


Our constraints



Discussion and Conclusions

- We have estimated the effects of $n-$body DM processes on the GC density profile (saturation).

- We have calculated the expected photon flux due to these processes.

- **We have set constraints on the DM self-annihilation cross section for the $\mathbf{n=3}$ case.**

Thank you for your attention!

Galactic DM density profile: Spike

$$\rho_{\rm spike}(r) = \rho_{\rm halo}(R_{\rm sp}) \left(\frac{r}{R_{\rm sp}}\right)^{-\gamma_{\rm sp}(r,\gamma)}$$

$R_{\rm sp} \simeq 0.34\,{\rm pc}$

Gondolo-Silk (GS)

Adiabatic growth:

- Peak:

$$\gamma_{\rm sp}(\gamma > 0) = \frac{9-2\gamma}{4-\gamma}$$

$$\gamma_{\rm sp} = 2.33$$

- Core:

$$\gamma_{\rm sp}(\gamma = 0) = 1.5$$

Stellar heating (★ heating)

Increase of DM velocity due to interaction with stars softens the spike:

$$\gamma_{\rm sp}^{\rm heated} = 1.5$$

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Bertone-Merritt (BM)

Similar to stellar heating, but instead of parametrizing effect in terms of diminishing γ_{sp}, make it a decrease in R_{sp}.

$$R_{\rm sp}(t) = R_{\rm sp}(0) e^{-\tau/2(\gamma_{\rm sp}-\gamma)}$$

Less stellar heating (★ heating-)

For r<0.01 pc, stellar density decreases substantially, so no interaction between DM and stars is expected below this point, so use GS.

Galactic DM density profile: Saturation

DM annihilations reduce the DM density: $$\frac{1}{m_\chi}\frac{\partial\rho(r,t)}{\partial t} = -\langle\sigma v\rangle\left(\frac{\rho(r,t)}{m_\chi}\right)^2$$

$$\rho(r,t) = \frac{\rho(r,t_{\rm form})\rho_{\rm sat}}{[\rho_{\rm sat}+\rho(r,t_{\rm form})]}$$

$\rho_{\rm sat} < \rho(r)$ → $\rho_{\rm sat} = \text{const. plateau}$

$\rho_{\rm sat} > \rho(r)$ → $\rho(r) = \rho_{\rm spike}(r)$

$\rho_{\rm sat}$ defines the critical density above which annihilations are important

(or equivalently $R_{\rm sat}$ defines the critical radius below which annihilations are important)

$$\rho_{\rm sat} = \frac{m_\chi}{\langle\sigma v\rangle t_{\rm BH}}$$

Galactic DM density profile: Saturation

But: $$\rho_{\rm sat}(r) = \rho_{\rm sat}\left(\frac{r}{R_{\rm sat}}\right)^{-0.5}$$

Not constant, but "weak cusp"

Existence of annihilation plateau, anisotropy

The previous derivation is too simple of an argument. DM velocity distribution needs to be considered. In annihilation region:

$$\rho \propto r^{-(\beta+1/2)}$$

0707.3334
1606.01248

where β is the anisotropy coefficient. **Plateau only if DM moves on circular orbits.**

Particle Physics Model (production)

Two processes: 1402.5143

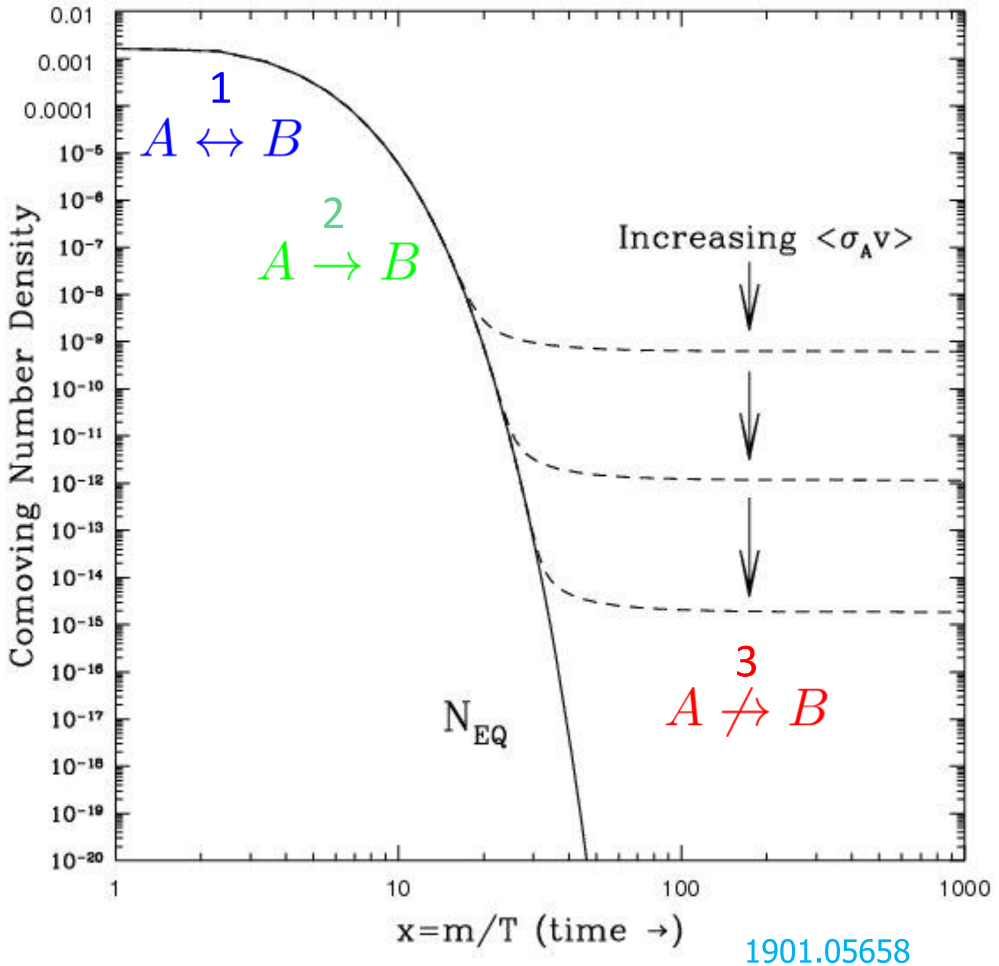
$\chi^n \to \chi\chi$: n-body interaction $\langle \sigma v^{n-1} \rangle$

$\chi\chi \to \gamma\gamma$: annihilation into photons $\langle \sigma v \rangle_{\text{ann}}$

DM production (Freeze-out process)

1. Early Universe: particles in thermal equilibrium with each other. Particle number stays constant.
2. Universe expands, cools: interactions less frequent. Particle number changes.
3. Interaction rate < rate of expansion of Universe: No more interaction, particle number stays constant.

$\langle \sigma v^{n-1} \rangle (m)$ which reproduces current DM density



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